A High-Brightness LPP EUV Source Based on Liquid Lithium Jet for Actinic Mask Inspection

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Outline

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- Products
- EUV LPP expertise
  - Tin alloy droplet approach
  - Lithium jet approach
  - Lithium scheme advantages
- Conclusion

ISTEQ: Overview

Spinoff from EUVLabs / RnD-ISAN:

- EUVLabs/Rnd-ISAN is a well-known research company (located in Moscow), which focuses on EUV light research activities
- Employees of ISTEQ/EUVLabs/RnD-ISAN are co-authors of 40+ EUV patents

Our main expertise: extremely high level of experience and dedicated team of engineers and scientists

- Plasma light source products and development for various applications
- EUV LPP/DPP light sources for semiconductor applications and metrology
- Metrology equipment for UV, EUV and X-ray
- Modelling and simulations of fundamental physical processes

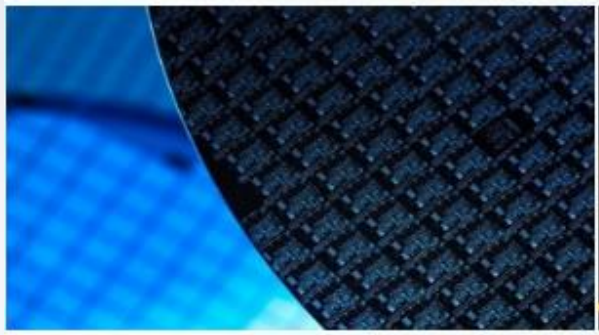
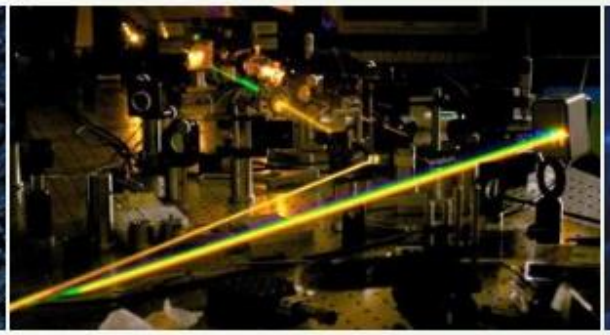
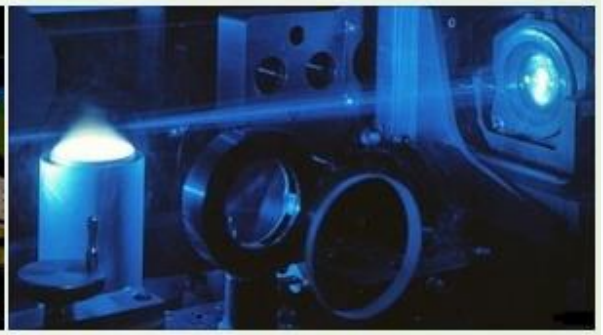
Company group ISTEQ/EUVLabs/RnD-ISAN includes 70+ R&D specialists

ISTEQ B.V. is located in the High Tech Campus, Eindhoven, The Netherlands

ISTEQ's mission

ISTEQ B.V. is an innovative high-tech company, which has developed a wide range of ready solutions for a variety of industrial applications worldwide. These applications are primarily for the semiconductor industry as well as material analysis and spectroscopy.

Our main focus is on the development and manufacturing of plasma light sources, spectroscopy and microscopy equipment for spectral regions ranging from X-ray to Infrared.

Metrology equipment for X-ray/UV/VIS/NIR

- Broadband plasma light sources (190-2600nm)
- Diffraction grazing incidence VUV monochromator-spectrometers (up to 80nm)
- On/Off-Rowland diffraction VUV spectrometers (3-36nm)
- Compact X-Ray spectrometers (0.04-1.6nm)
- MCP detectors for plasma visualization in EUV-VUV spectral region

Plasma light source XWS-65

Broadband plasma light source:
- Extra wide spectral range
- Ulta high brightness
- High stability

VUV spectrometer AGS

Amplitude grating spectrometer for quantitative measurements ranging from 6 up to 200 nm.

MCP Detector

We provide a complete program of gated MCP (micro channel plate) detectors for visualization of X-ray and VUV radiation.

X-Ray Spectrometer HD-1

Extra compact X-Ray spectrometer which provides absolute spectral measurement of low intensity X-ray radiation sources, X-ray fluorescence

VUV Spectrometer GIS

A new type of grazing-incidence VUV spectrometer with extended spectral range (up to 80nm), provided by a specially designed grating.

Rowland's Spectrometer

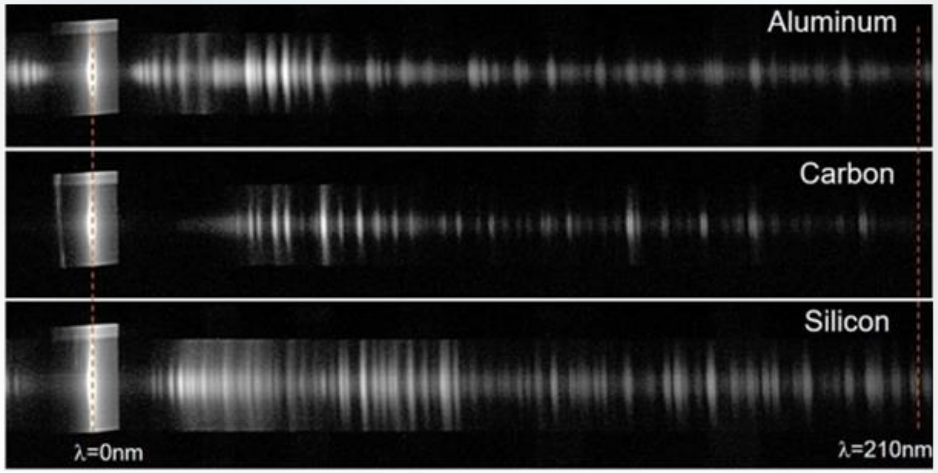
Grazing incidence spectrometer built in the Rowland circle configuration. This compact instrument allows the user to obtain a high quality time resolved spectra between 3 and 36nm.

XUV-VUV spectrometer AGS

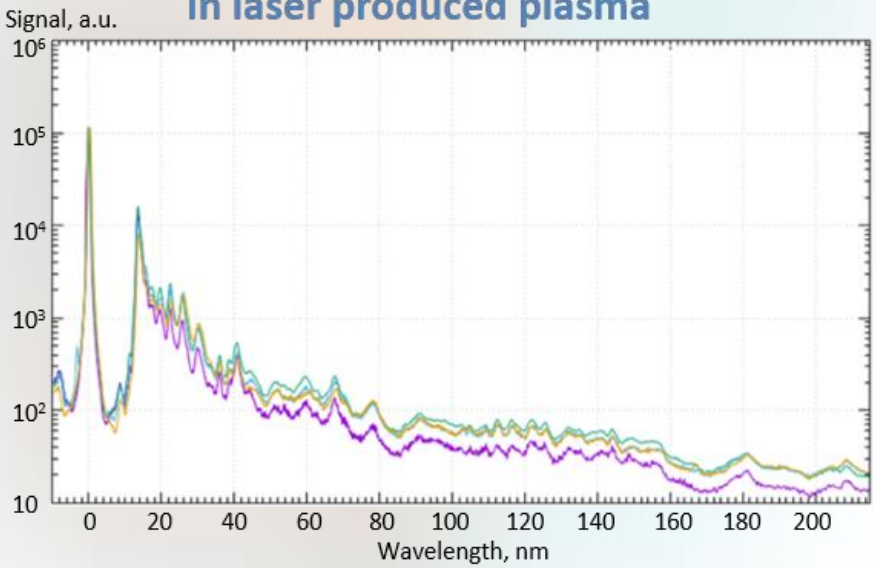
Amplitude Grating Spectrometer AGS for absolute measurements:

- Grazing incidence amplitude grating which provides spectral range from 6 up to 200nm
- Spectral resolution: $\lambda/\Delta\lambda = 50$
- High quantum efficiency CCD
- Compact design

Images of spectra acquired by AGS

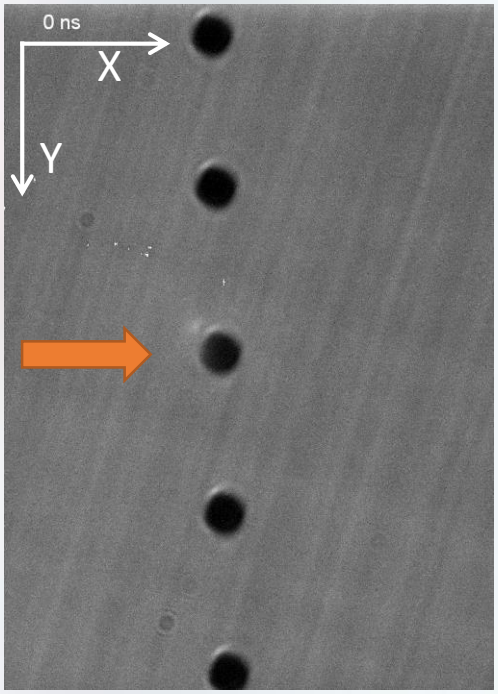


AGS line-resolved spectra of light elements in laser produced plasma



Expertise in high-brightness EUV LPP light metrology sources

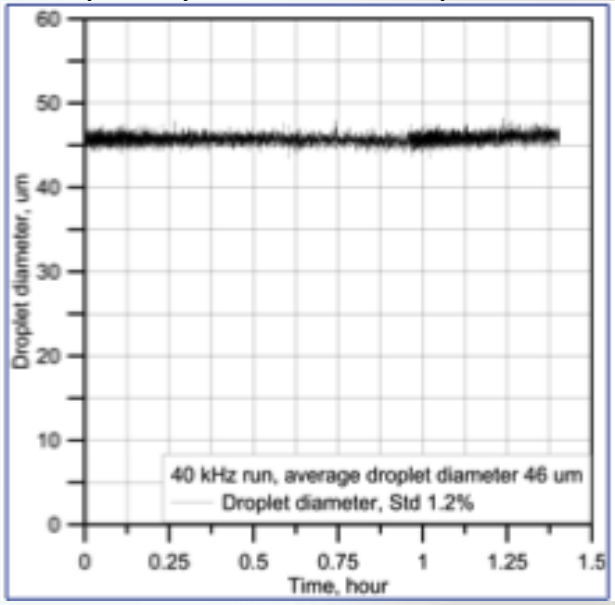
EUV source: Tin alloy droplet generator

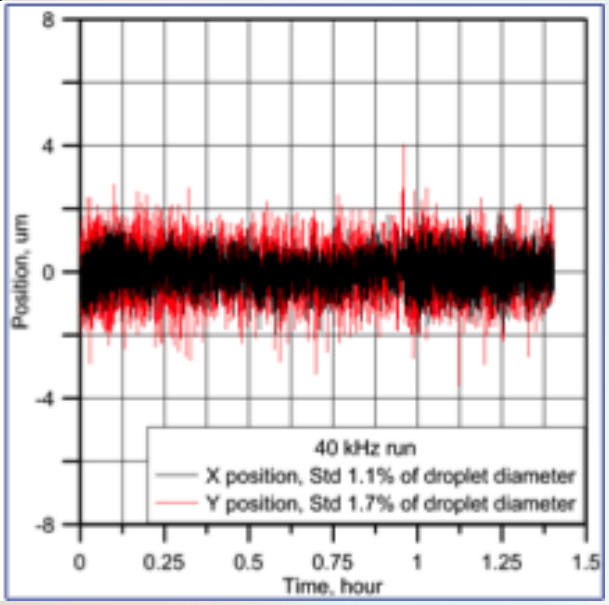


Click to play video

Droplet Ø: 46um Spacing: 175um

Frequency: 40kHz Droplet velocity: ~7m/s





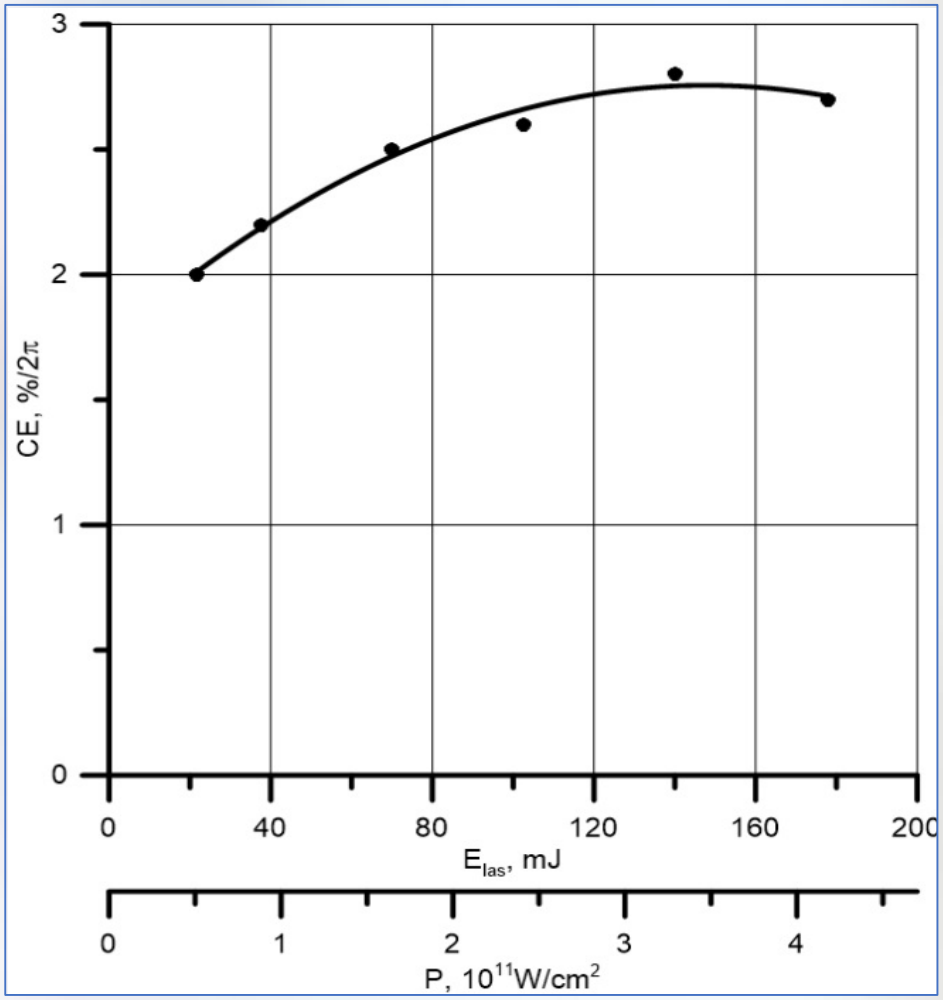
Center of mass displacement:

σ_x = 0.5 um; σ_y = 0.8 um (1,5 hour)

High target position stability!

Low-temperature tin alloy was used as a target, which allowed us to run the droplet generator at a lower ambient temperature. This provided higher stability while keeping the brightness of the LPP source at the same level.

EUV energy stability



Average CE: 2.5%

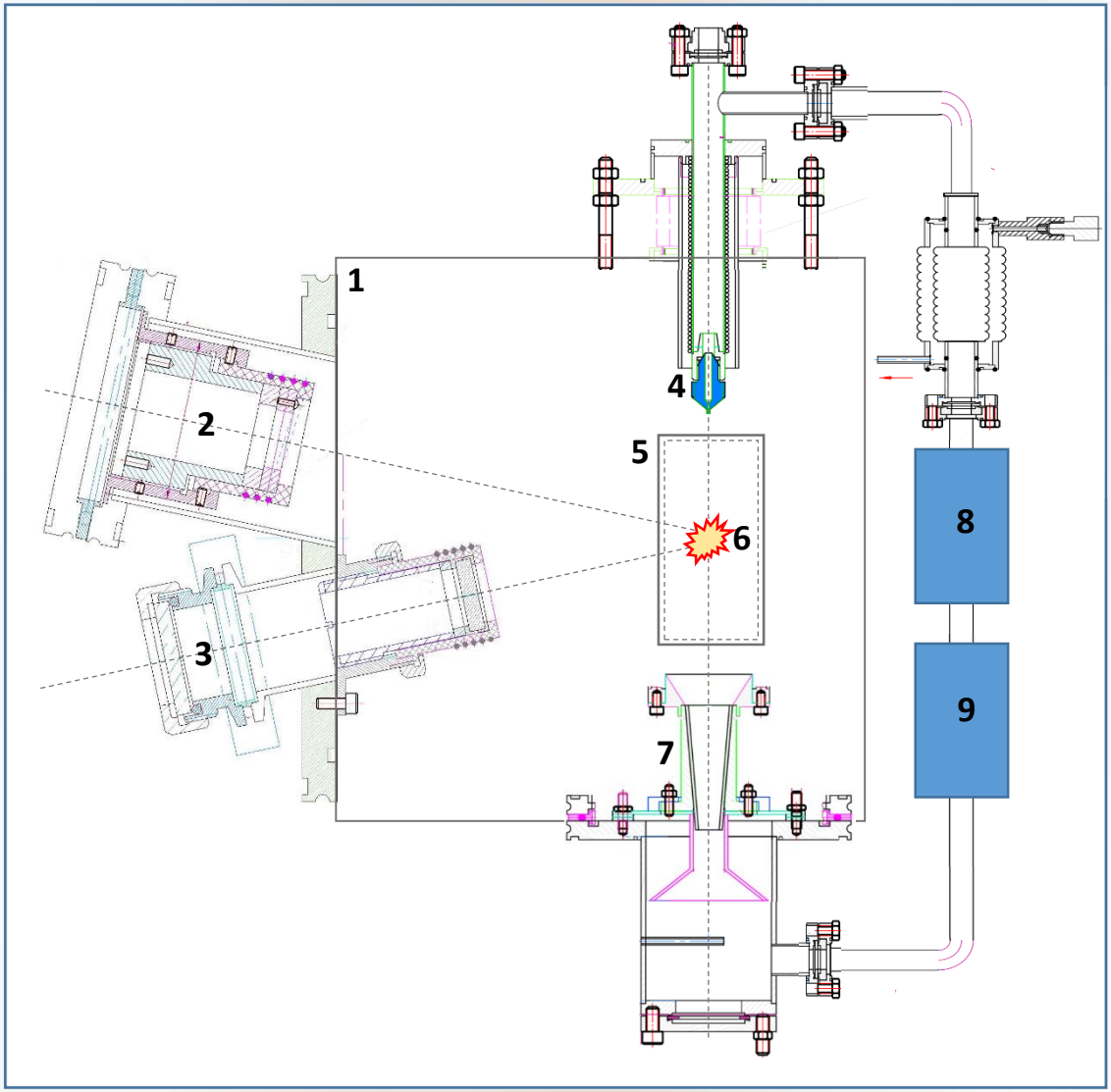
The latest results published: ***"Stable droplet generator for a high brightness laser produced plasma extreme ultraviolet source"***, Review of Scientific Instruments 87, 103304

EUV metrology source based on an innovative Lithium jet approach

Compact Li target design

Source components:

1. Vacuum chamber
2. EUV output window
3. Drive laser input window
4. Lithium jet nozzle
5. Plasma/jet protection unit
6. EUV plasma
7. Li-catcher unit
8. Lithium filter
9. Lithium pump



Schematic picture of Li EUV LPP source

New concept of EUV light source

Source components :

- Target: continuous Li liquid jet
- Self cleaning drive laser and EUV windows
- Recycling target system

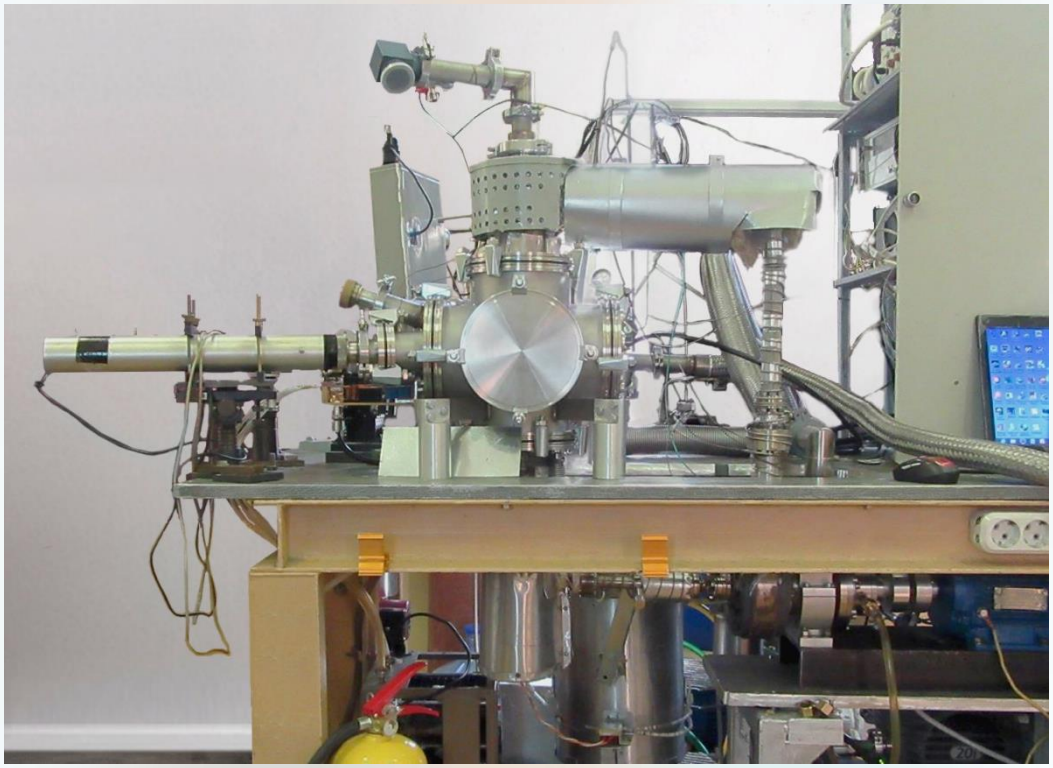
Main source parameters:

- Wavelength: 13.5nm
- Etendue: 2-4·$10^{-5}$$mm^2$·sr
- Input laser power: up to 1kW

Expected EUV source characteristics

For drive laser: 1064nm, 1kW, 10kHz:

- Collectable in-band power: >60mW
- Expected EUV brightness: **up to 1 kW/mm^2·sr**

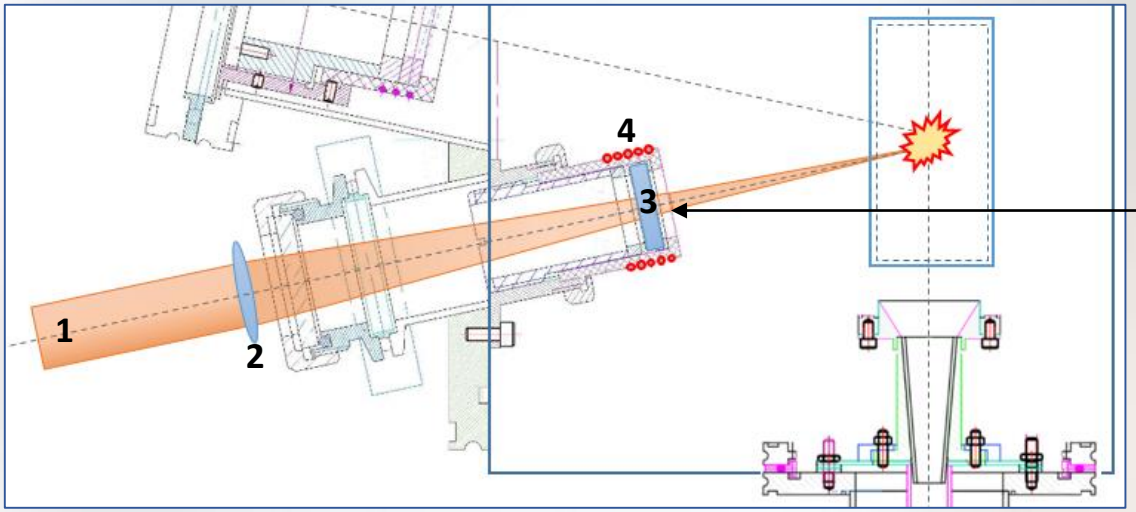


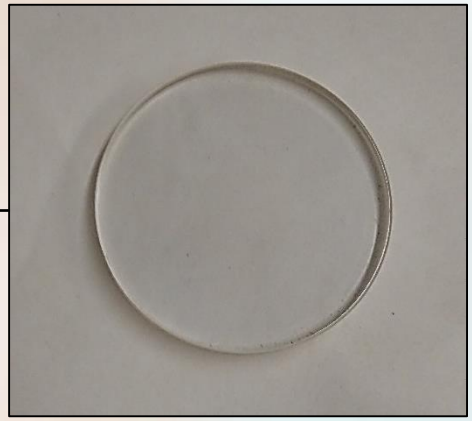
The source prototype is currently in the R&D phase.

The main innovative solutions have been patented* and have been demonstrated via independent experiments in our R&D facilities.

*: High brightness LPP EUV light source is covered by patent (United States Patent 9476841)

Drive laser input window





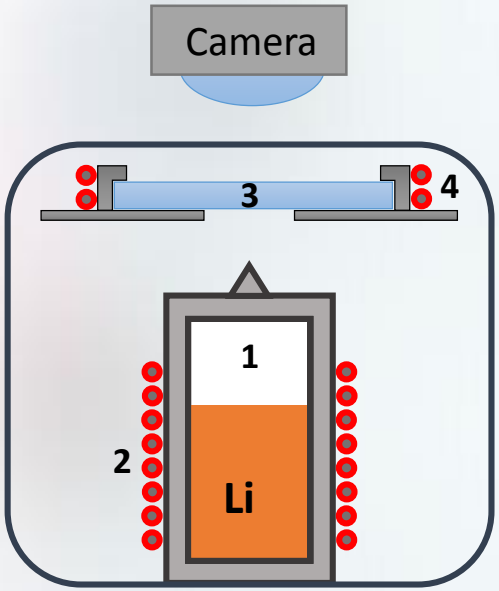
Main components:

1. Drive laser pulse
2. Focusing lens
3. Protection “self-cleaning” window
4. Window heating system

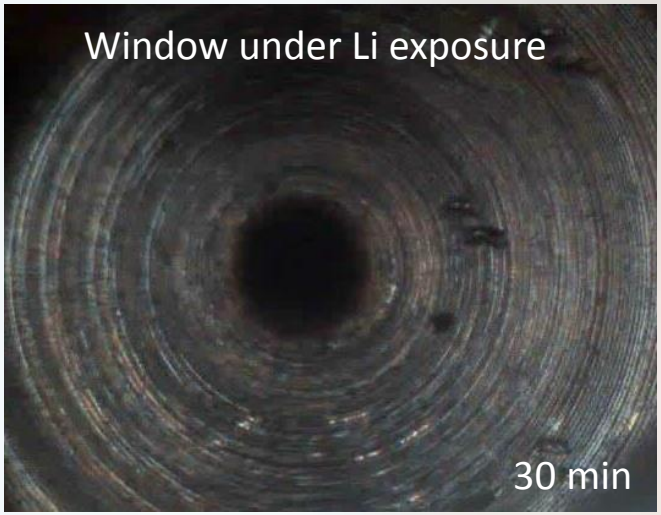
Main features:

- Self cleaning window made of specially treated sapphire. This material does not react with Li in aggressive liquid/vapor hot phases thus maintaining high transmission for the drive laser radiation
- Heating system provides temperatures up to 530°C
- Special features allow the window to be that hot, while keeping the surrounds at a reasonable temperature

Proof of concept: experiment and results

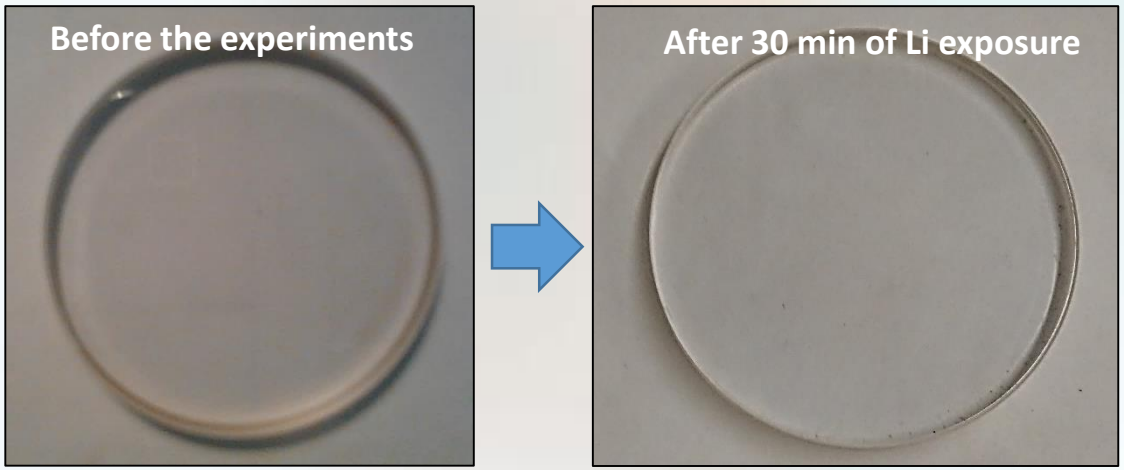


1. Reservoir with liquid Lithium
2. Heating system (up to 470C)
3. Laser input window
4. Heating system (up to 530C)

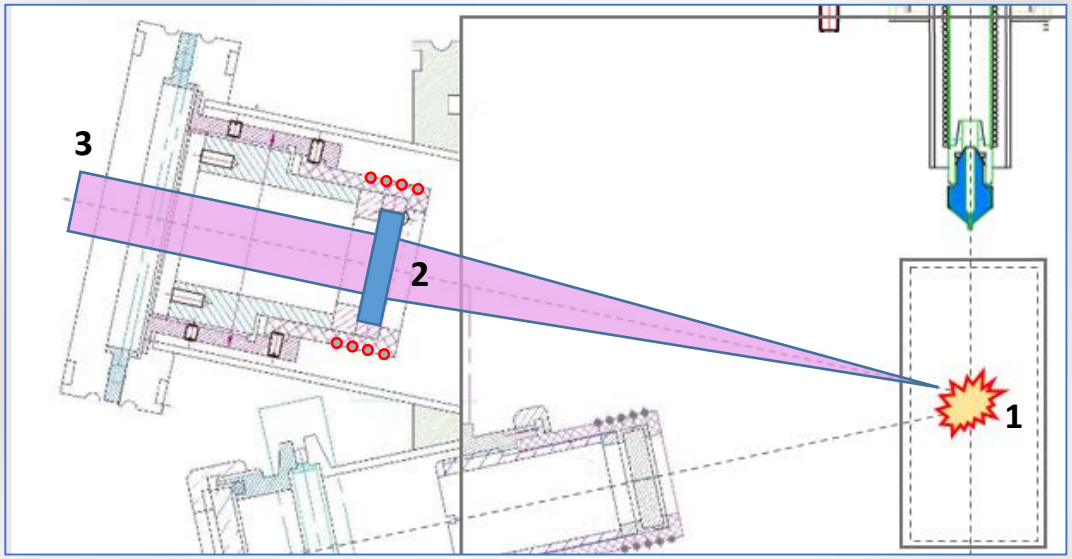


1. Li heats up to 470 °C
2. Li starts to evaporate
3. Condensation on sapphire

1. Window heater turns on
2. Window heats up to 530 °C
3. After ~2 mins the heater turns off



EUV output window



Main components:

1. EUV plasma
2. EUV output window
3. EUV output light:

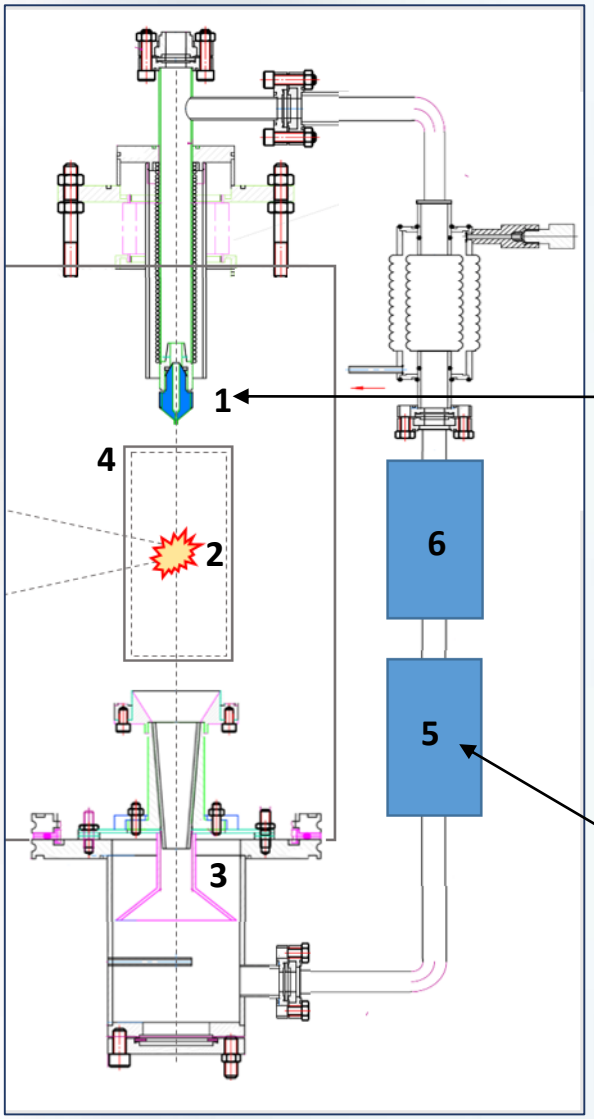
Main features:

High temperature resistant EUV window with improved mechanical resistance.

EUV output unit characteristics:

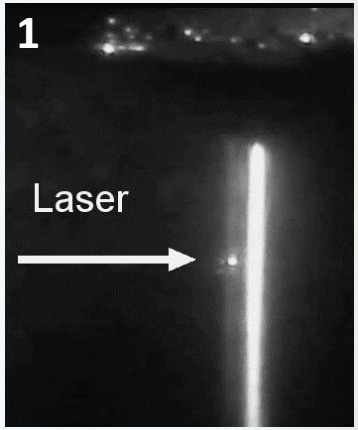
- Output window area: 3cm^2
- Plasma-window distance: 16cm
- Output solid angle: 0.012sr
- EUV output window transmission: 50%

Lithium closed loop



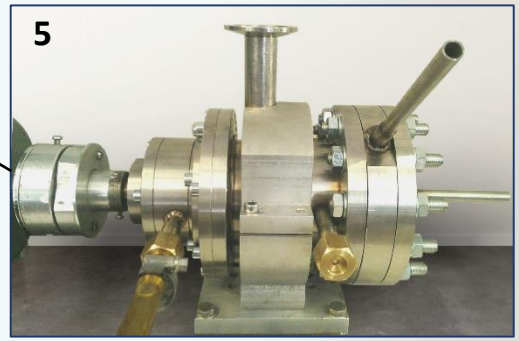
Main components:

1. Lithium jet
2. EUV plasma
3. Lithium catcher
4. Plasma/nozzle protection unit
5. Lithium pump
6. Lithium filter



Jet parameters:

- Lithium jet velocity: up to 20m/s
- Diameter: 1mm
- Distance nozzle-plasma: 50mm
- Jet approach provides extreme stability, renewable and infinite in space target



Pump operational conditions:

- Temperature up to 350°C
- Pressure up to 1 atm
- Liquid lithium is pumped in a closed loop, which makes refilling and cleaning of the lithium unnecessary

- The system is designed to keep the Li jet an extremely stable and constantly refreshable target for EUV plasma generation

*: Liquid metal pump is covered by patent (WO2013/157985)

Why Lithium?

We have identified the issues and have come up with the solution of laser produced plasma using a Li jet target:

- **Li target has minimal and manageable debris in comparison to the Sn target:** due to the "closed LPP chamber" design using self-cleaning radiation input and output windows
- **Long source lifetime:** special optical design allows the placement of the collection EUV optics outside the LPP chamber
- **High spectral purity:** usage of Li plasma with narrow "in-band" line spectra, concentrated at 13.5nm
- **EUV dose stability:** provided by stable position of the target and its infinite size (in comparison to the "Tin droplet generator" concept)
- **Long (infinite) duty cycle:** provided by continuous operation of liquid lithium pump.
- **Relative system simplicity**: easier to handle and to recycle, no vacuum chamber opening or optic cleaning is needed
- **Compact design and expected reasonable price**

Conclusion

- Two approaches of EUV targets; tin alloy droplet and lithium jet have been addressed by ISTEQ and its partners.
- Both approaches' feasibility were demonstrated and have shown good performance.
- Li jet approach has shown high potential suitability for mask inspection due to its simplicity and repeatable performance.
- ISTEQ is looking for a potential partner/system integrator to take this technology to the next level.

Thank you for
your attention